Lectures on
Elementary Particle Physics
and Philosophy of Science

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P.T.O

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and Heisenberg

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Recommended books

The nuclear apple: PT Matthews.

Govinan: Particles, Accelerators:

Hegelian philosophy on

"Non-being -- is a void defined by its surrounding it as infinity evident de being."

Perkins: Introduction to High Energy Physics

Gasiorowicz: Elementary Particle Physics.

Auxiliary reference books on Elementary Particles

(3)

Heitler : The Quantum Theory of Radiation

Bjorken, Drell : { Relativistic & Neclear Fields

Martin, Spearman : Elementary Particle Theory

PdR Ruiz : Hadron ~~Physics~~ Interactions

Marshak, Sudersahan : Elementary Particles

Hamilton : The Theory of Elementary Particles

Roman : Theory of Elementary Particles

Collins, Squires : Regge Poles, particle Physics

Chew : The S-matrix theory of Strong Interactions.

Chew, Jacob : Strong Interaction Physics

Chew : The Analytic S-matrix

Omnes, Froissart : Mandelstam Theory, Regge Poles

Omnes :

Taylor : elementary Particles.

~~Schröder~~

Schröder : An Introduction to relativistic quantum field Theory.

Bernstein : Elementary Particles, their Currents

Kokkedee : The Quark Model.

Schecker, Rolnick, Weinberg. Nussen, Fields

Frautschi: ~~Introduction to~~ Regge Poles, S-Matrix Theory

Squires: Complex angular momentum, Particle Physics

Newton: The Complex-J-Plane.

Gell-Mann, Neeman: The Eightfold way.

Umezawa: Quantum Field Theory

Hepp, Thirring: Elementary Quantum Field Theory

Pauli: Meson Theory of Nuclear Forces.

Wentzel: Quantum Theory of Fields

Gourdin: Unitary Symmetries

Carruthers: Introduction to Unitary Symmetry

Javel, Rohrlich: The theory of photons, electrons.

Streater, Wightman: P.C.T., spin, and statistics, and all that.

Källen: ~~Quantum electrodynamics~~ Elementary Particle Physics

Muirhead: The Physics of Elementary Particles.

Adler, Barker: covariant Algebra

Eden, Taylor, Landshoff, Polkinghorne: The analytic S-matrix

Eden: High Energy Collisions of Elementary Particles

Akhiezer, Berestetsky: Quantum Electrodynamics

Text: The general theory of quantized fields.
Bogolubov & Shirkov, Introduction to the theory of quantized fields.

Randall: An introduction to Quantum Field Theory.

~~Roman: Theory of elementary particles~~

Mayhoff Neeman Physics

Bjorner: Introduction to Q.E.D

Horn & Zacharasen: Hadron Physics at very High Energies

Heisenberg: Introduction to the Unified field theory of elementary Particles, 1966

Schwinger: Quantum electrodynamics (Dirty Q.E.D)

Leon: Particle Physics. an introduction

Brandeis: The fundamental particles

Linden Baum: Particle Interactions Physics at High Energies (recommended)

Burchhardt H. Dispersion Relation dynamics

Feng: Theory of Lepton-Hadron Processes at High Energies

Gross, Violini: Dispersion theory in High Energy Physics

de Alfaro, Fubini, Furlan, Rossetti a.
Bertlmann: Current in Hadron Physics

Bertlmann, Martin: Causality

we shall suppose that correspondence between theories can be reduced to three basic types:—

① Reformulation: the L theory is derived by first reformulating the S theory, which then gives a duo to an observable (e.g. potential) exchange

modification: Ex: 1) N-particle theories with variable N and 2nd quantization

2) Feynman diagrams by adopting spacetime point of view in place of Hamiltonian + then powerful natural framework for the renormalization programme

3) analytic structure of theory from perturbation theory leads to analytic S-matrix theory

② Analogical Extension: we extend theory by trying same device again that has worked before ex 1) Studies new quantum #'s such as strangeness

2) Go from SU(2) to SU(3) for symmetry classification

③ Simple modification: one aspect of a theory is altered ex (1) Maxwell Eq. to Klein Gordon Eqn. for the field of a particle with mass m_0.

(2) Galilean invariance → Lorentz invariance

① is a variant of ②, ③ which often provides a powerful first step in developing a research programme

* Aristotle thought all change was natural
(Galileo) Newton thought that one could conceive of some changes as un-natural i.e. the concept of Scientific Law includes & indeed arises from the concept of breaking a Scientific Law.

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3 types of Science

Paradigm shifts — new philosophical conceptual framework

* Reformulation — given new outlook on an existing set of concepts

Normal Science — work outs detailed application of an accepted framework of ideas with possible use of low-level auxiliary hypotheses.

(* we might refer to reformulation as directional shifts within a paradigm (or as lateral shifts))

centre the traditional atomistic programme
of Greek Atomism in the line of development
Greek atomism → 17th atomistic revival
(Gassendi, Boyle) → Scientific atomism
of the 19th century (Dalton in chemistry,
Kinetic molecular theory of matter.

Our hope is to link broadly essentially
with the atomistic approach to
theoretical explanation. This will be carried
by considering the essential open-endedness of ept.
and the philosophy of the bootstrap and the inadequacy of the unified
Containment model (cf Feynman)

Topics we shall not discuss include

1) reality of theoretical entities
2) theory of measurement in Scientific Quantum
Q. mechanics, interpretation of commutation
relations as in classical work of Born &
Rosenfeld
3) The role of symmetry in particle physics
this implies constituents or a complete theory, but is no substitute for
a complete theory

---

(4) Relation of theory to experiment
on the question. How experiments on theory
played the major role in ept development
of crucial experiments

By E.P.P we shall understand the study of
Scientific processes i.e. the constitution of
atoms in the way that atomic theory corresponds
to constitution of matter.

*

Désintégration de weak interaction :

leptonic : $K^+ \to e^+ + \nu_e + \bar{\nu}_\mu$

semi leptonic : $n \to p + e^- + \bar{\nu}_e$

non leptonic : $\Lambda^0 \to p + \pi^-$

as a modification & extension of some formulation
of S and also heuristically this is seen
as a natural approach to the transition by
the corpus of scientific opinion which gives
the seal of orthodoxy to the theory.

The psychological notion of the first unveiling
of a new theory is something which can
& should be distinguished from, & what
I shall call the Platonic heuristic involved
in a discovery.

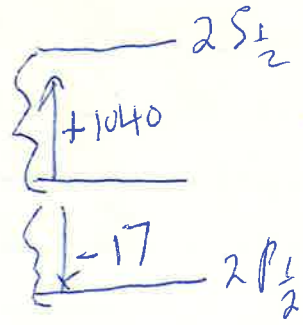
But if two theories can be logically related
or described, but the Platonic heuristic is
certainly quite different, then I shall say
the theories are not in correspondence
in my sense

eg's Ptolemy
Copernicus, Kepler
Newton & Aristotle. *
Einstein & Galilean relativity
quantum theory, classical mechanics (and outside in respect of wave mechanics)
wave, corpuscular theory of light
thermodynamics & statistical mechanics

These constitute
these constitute paradigm shifts in the Kuhnian
sense and can only be expected on encounter
of logical, heuristic correspondence by a distortion
of the the consensus of historical opinion.

eg's ① Boolean lattice → Non-distributive lattice & projections
or correspondence & classical & mechanics

Early references evaluated for Lamb shift:
Pasternack (1938), (Kuhn) Series (1950) confirmed to within 5%)



Lamb shift: Exp 1953 1057.77 ± 0.10

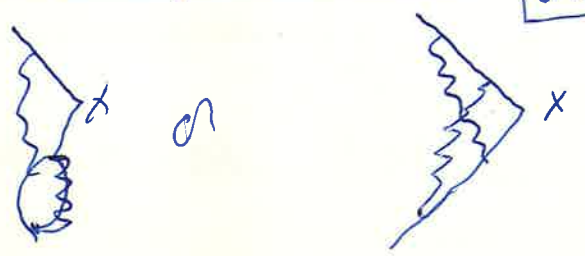
Bethe 1947 → 1040 Mc/sec

Kroll-Lamb, French-Weisskopf: 1949 → (also Feynman, Fukuda, Miyamoto & Tomonaga) 2nd order effects
→ 1052

Barringer, Bethe & Feynman, 1951
Kusch, Millman & Scheringer, 1952 (quoted in S & R)
Barringer, Dyson, Salpeter
Bersohn, Wenneser & Knoll → 1058 ~~1057.99 ± 0.2~~ 4th-order effect
Salpeter (1953) → (1057.19 ± .16 quoted in Salpeter's paper) record of nuclear-
~~French~~ Fried & Yennie, & Layzer 1960
→ 1057.70 ± 0.15

* Anomalous magnetic moment:
Exptl. (Crane & Steinberger 1953)
0.00 1159 557 ± .000 000 30
Theor 0.00 1159 641 ± .000 000 003
Expt: 0.00 1159 644 ± .000 000 067
Wesley & Rich (1970)

Kusch & Foley 4th-order magnetic moment



theory > experiment > technology ; ifted determine profession.

DATE	Theory	Experiment	Technology
1897		e⁻ (cathode ray)	High vacua
1911	Rutherford model (1913)	Nuclei (Rutherford)	geiger & Marsden 1909
1913	proton structure of nucleus (Moseley)	X-ray spectra	crystal spectrometer
1905	Photon Einstein		
1932		n (discovered)	
1930	Dirac positron (proton?) (rel. eq. 1928)		
1927/30	B. field theory deuteron Dirac, Jordan, Pauli, Jordan, Wigner, Heisenberg, Jordan, Pauli (1927, 1929, 1930, 1932, 1933 recalled)		
1934	Neutrino (Fermi) (after Pauli 1931)	e⁺ (1932) (Blackett & Occhialini)	Blackett counter controlled cloud chamber
1935	Yukawa predicts meson (recalled)	decay of (Anderson)	
1943	Heisenberg S-Matrix	μ (Anderson, Neddermeyer 1936)	
1947	Pauli spin-statistics theorem	π (Powell, Occhialini)	plate emulsion
1948		(1947) Lamb shift (Lamb-Retherford)	artificial mesons (1948)
1949	Schwinger, Feynman diagram, Dyson's theory	$2P_{\frac{1}{2}} - 2S_{\frac{1}{2}}$ shift Fermi-Dirac statistics	
1950	~~Kallen's book out~~	artificial mesons	High energy accelerators
1952/3	~~Brueckner, Feynman, Gell-Mann~~	Λ (Rochester, Butler) (1947)	
1955		artificial (1955)	K, Σ, Ξ (1947–1953)
1956	Non-conservation of parity suggested Yang, Lee		Bubble chamber (Glaser 1950)
1953	Gell-Mann's Strangeness Q.N. Lüders' theorem (CPT 1954)	Wu's experiment (1957)	
1956	~~Chou, Low~~ TN scattering	ν_e neutrino verified by Reines & Cowan (1956)	~~300 GeV~~
1957	~~Chou, Salzberg, Wouthuysen~~		
1958	The Mandelstam ~~representation~~ variables etc. ~~legs~~ ~~particles~~ ~~scattering~~ applied to S-matrix		

CERN Brookhaven	1961	30 GeV
Berkeley	1968	70 GeV
Batavia	1973	300 GeV
N.A.L.		
CERN	?	

1960

Chew, Mandelstam

1961

Chew, Frautschi introduced the bootstrap (projectors, leading singularities, equal-mass scattering in S & U)

1963 — discovery of Σ_c (resonance)

1959

Regge poles, Trajectories introduced the concept of angular momentum

1961

Unitary symmetry (Gell-Mann - Neeman) → Ω^- (1964)

1964 quarks (Gell-Mann, Zweig)

1968

Duality of resonances, trajectories
F.E.S.R. bootstrap

1968

Veneziano model

Stanford, Brookhaven, CERN, Fermilab, Serpukhov, Novosibirsk, 500 GeV — I.S.R. (1966 – 1971) 30 GeV

1969 –

Partons (Feynman)
model of the proton (deep inelastic e-p scattering)

1962 – 1965

Current algebra (Gell-Mann, Adler-Weisberger calculation of axial vector coupling constant of β-decay)

1973

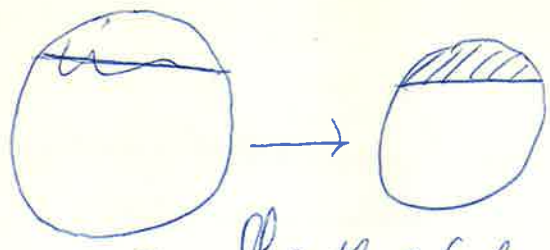
Neutral currents (Weinberg, Salam, Ward)

1964

Non-existence of $Cl(10, \mathbb{C})$ the Lie algebra of $SU(3)$ (Christenson)

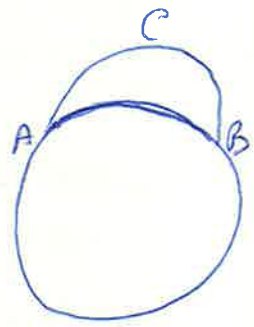
1968–73 Recent developments include the duality of resonances, trajectories, the F.E.S.R., Bootstrap, Veneziano Model, Feynman's Parton model of the proton.

Modification



II area of the modification — general explanations [illegible] a small region in an odd manner. Chronological detail in novelty is vital for + point. Eg Non-party Conservatives in the wash interviews:

Analogical extension



sector A B walks well to extend it along A C B as in S. U. 3. Chronological detail or novelty is here of vital importance

1 Both modification > analogical extension are really sub-categories of Normal Science

We shall take 3 philosophical points & discuss them within the context of elementary particle physics

(1) Inter theory relationships: we shall view the progress of theories about elementary particles against the background of the general Correspondence principle which we shall take as the theories that new theories incorporate the structures of old theories over & above the necessity for merely saving the phenomena.

We shall introduce the ~~formulation~~ ~~hypotheses~~ hypotheses to suggest how theories in e.p.p. are logically and historically related, i.e. we ~~are~~ are interested in the question of a.) historical heuristics b.) rational reconstruction of theory development

We shall suggest these two aspects can be made ~~logically~~ to coincide in e.p.p.

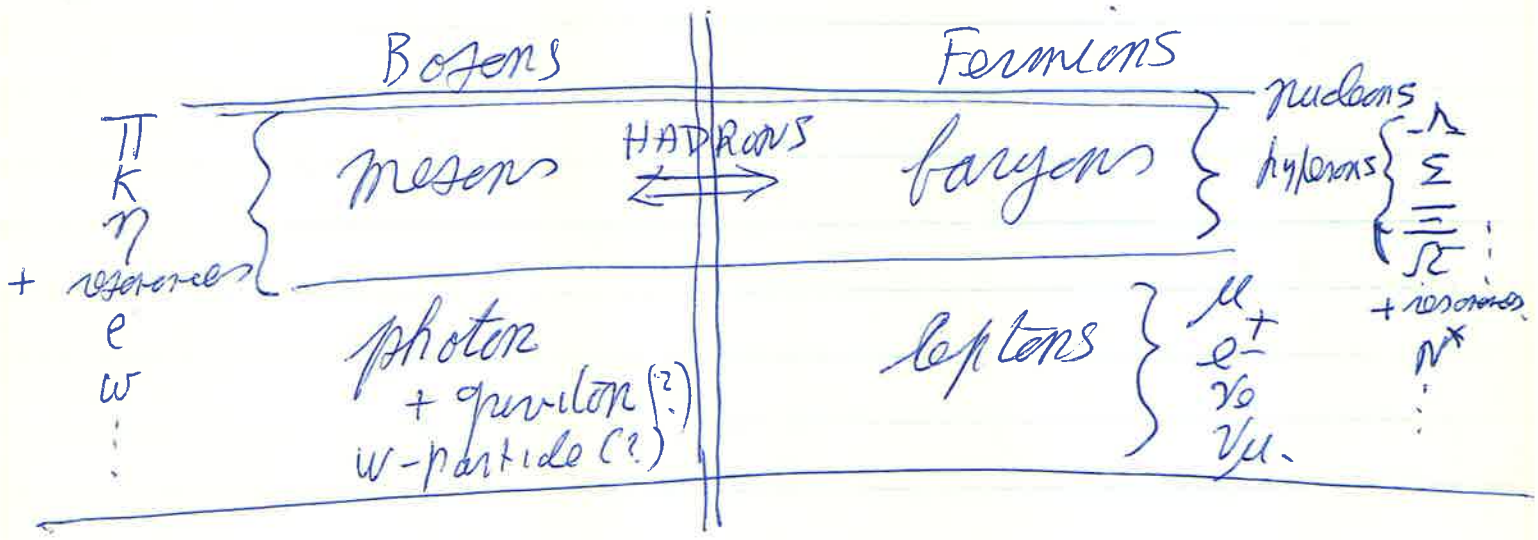
(2) Predictive power, verisimilitude: we shall outline some of the successes of the theory & discuss the question of the significance of successful prediction in a subject where the theory or a whole is rather unsuccessful, at any rate for strong interaction theories We will stress here the computation gap, the question of crucial experiments the question of whether experiments are guided by theory, a theory used to explain experimental results, which are piled up independently.

1929 — Relativistic α-decay (Gamow, Condon)

1949 — Feynman diagrams (Feynman)

1958 — The analytic S-matrix (Mandelstam)

Particles



Interactions — Strength — range

Strong — 15 1 hadrons. decay 10^{-23} sec

electromagnetic — 1/137 (10^{-2}) ($e^2/\hbar c$) — ∞

weak — 10^{-13} G/ħc — 10^{-13} cm short ($<10^{-15}$ cm)

Gravitational — ~~10^{-40}~~ ~~10^{-38}~~ 10^{-39} $\left(\frac{G m_p^2}{\hbar c}\right)$ (for two protons) — ∞

"Stable" particles decay through weak interaction

life time $\sim 10^{-10}$ sec.

unstable — decay thru strong interaction $\tau \sim 10^{-23}$ sec $\sim 10^{-13}/c$ = time for particle to cross strong interaction

Σ^0 $\xrightarrow{\text{strong}}$ $N\bar{N}$ $\xrightarrow{\text{weak}}$ $\mu\bar{\nu}_\mu$.

$\sim \Delta E = 100$ MeV

Pions first produced artificially in 1948
using the Berkeley synchro-cyclotron

Kaons . . . in 1955 using
the 6 gev Bevatron at Berkeley (antiproton beam)

artificial production of V-particles first made
possible by the 1.4 gev proton synchrotron at (Cosmotron)
at Brookhaven, 1953

Lamb shift

Semiclassical derivation by Kramers (1947)
reported at Solvay Conference 1948.
preceded experimental discovery
according to Heitler
followed experimental discovery
according to Schaefer.

Magnetic moment

Schwinger 1949 $D\mu = 0.001161$
Karplus, Kroll. $D\mu = 0.001145$ (1950)
Sommerfeld, Petermann, Kroll } 1957 $D\mu = 0.001596$. (corrected Karplus, Kroll's work)
later report to α^3 $D\mu = 0.001159641 \pm .000000003$ new terms from α^3
(corrected by Karplus, Klearmon)

Experiment Nafe, Nelson, Rabi 1947, Bretscher (1947) attributed to D Hebb.
Hyperfine structure
More precise work by Foley, Kusch (1947-48) – 2 exp. of effect
By 1952 (Kusch) experimental value $.001146 \pm .000012000$
by 1961 Pidd (rotating pol. free electrons in a magnetic field) $.001609 \pm .000002400$
1963 Wichmann, Crasemann $0.001159622 \pm .000000027$
1963 (revised by Rich) $.001159557 \pm .000000030$
1970 Rich $.001159644 \pm .000000007$

Quoted on Lamb shift

(1) Did Kramers know of Lamb expt in 1947 (cf Silvay Conference 1948)

(2) Did Lamb know of Bethe's work (cf Lamb 1947) yes

(3) Latest measurement on Lamb-shift

(4) What do Wesley, Rich (1970) say about Triebwasser, Steinberger (1968) re anomalous magnetic moment of the electron? Cannot explain

g-factor for muons

$\left(\frac{g-2}{2}\right) =$

Expt: Bailey et al. (1968) $(116616 \pm 31) \times 10^{-8}$

Theory: 116557.4×10^{-8}

This discrepancy is still unexplained

Lautrup, Peterman, Rafael. (Science of Myron Letters)
Physics Reports vol 3C no 4, May/June/72.

Lamb Shift: Theory 1057.911 ± 0.012

Expt. 1057.90 ± 0.006 (86) 60 ppm

Lamb (1953) (corrected 1970) → Robiscoe & Shyn (1968) revised 1970

$(g-2)/2$ elec. Theory $(1159655.4 \pm 3.3) \times 10^{-9}$

(Wesley, Rich revised) Expt $(1159657.7 \pm 3.5) \times 10^{-9}$

$(g-2)/2$ muon Theory ~~1057.911 ± 0.012~~

Expt ~~1057.90 ± 0.006~~

Bradley & Cleland $(1165879 \pm 15) \times 10^{-9}$

$(1166\underline{16} \pm 31) \times 10^{-8}$ (not pure Q.E.D.)

Hyperfine structure v. accurate expts, but theory difficult, not as accurate as expt. but good agreement discrepancy 2.5 ppm

Positronium
} Good agreement.
Muonium

Summary Low energies accuracy in both : theory
→ 1 part per million

Good overall agreement to within 3 s.d.

Theoretical g_μ is known to 13 place
pure accurate exp. beyond (Theory dept at CERN)

Lord Kelvin 12 Mar. Uber. Unreasonably is
5 x smaller than experiment

Title is Recent developments in the comparison
between theory & expts in Q.E.D.

Latest calculation of $\left(\frac{g-2}{2}\right)_e$ to 6th order : comparison with exp.
is Levine & Wright (1973) P.R. D 8 p 3171

→ $\left(\frac{g-2}{2}\right)$ theory $= (1159651.9 \pm 2.5) \times 10^{-9}$ theory
$= (1159656.7 \pm 3.5) \times 10^{-9}$ Expt.

agreement is described as fairly reasonable
(note downward shift in expt.)

Bethe (1947) P.R 72 339. refers to Pertenoch who used after no reasonable explanation of the discrepancy

Schwinger, Weisskopf, Oppenheimer Rose suggested shift due to interaction with the radiation field. refers to the Shelter Island Conference in 1947 where all these problems were extensively discussed ('Theoretical Section of the conference)

Lewis (1948). N.R. 73, 173
was first to extend Bathe's idea to Coulomb
scattering corrections.

Walker (194) N.R. 74, 1157.
explores Lamb shift etc in terms of a
meson eq. amplitude & radiation of an
electron coupled to the Zero-point fluctuations
of the field — the disturbance of the charge
current density gives rise to observable
effects (of dimension on Heitler, Fleming)
— related also to theorems of Spontaneous
radiation.

Efimov, Maglyshev, Rogalska, Vorontsov, Yu.

Nucl. Phys B (1973) 59 (1) 1–22.

Correction to last slide due to current-current
weak interaction.

Layzer (1960) P.R.L. 4 580.
gives following Table

	H	D	He^+
Item	1057.70 ± .15	1058.96 ± .16	14046.3 ± 3.0
Salt	1057.77 ± .10.	1059.00 ± 0.10 (1953)	14040.2 ± 4.5 (1957)

So results are ~~a~~ v. good agreement with theory

Erickson et al. has calculated Lamb shift for Be^{III}, C^{V} ; agree with experiment ~~results~~ results on theory based on 2-electron ions by Layzer & Bahcall ; agrees. to within 30 ± 20% estimated.

P.R.A (1973) 8, 1651

Lamb P.R. 79, 549 (1950)
also the Breit Brown P.R. 74, 1273 (1948)
for explanation that Rydberg standard cannot
explain the Lamb Shift.

For Zeeman effect $H' = \mu_0 (2H + 2S \cdot H)$
$\mu_0 = e\hbar/2mc$

Breit for hydrogen structure
where A is not constant
~~$H = (g_I I \cdot \times \frac{S}{2})/13$~~ $A = (\mu + \Omega)/13$
H = same A, but on Dirac Eq. ; solve
gives perturbation depends on α

$$I \cdot J = \frac{1}{2}\left[F(F+1) - I(I+1) - J(J+1) \right]$$

$I = 1/2$, $J = 1/2$

$F = 1$ or 0

and $\Delta(1S_{\frac{1}{2}}) \simeq 1416$ Mc/sec
$\Delta(2S_{\frac{1}{2}}) \simeq 177$ Mc/sec
$\Delta(2P_{\frac{1}{2}}) \simeq 60$ Mc/sec

good general background account

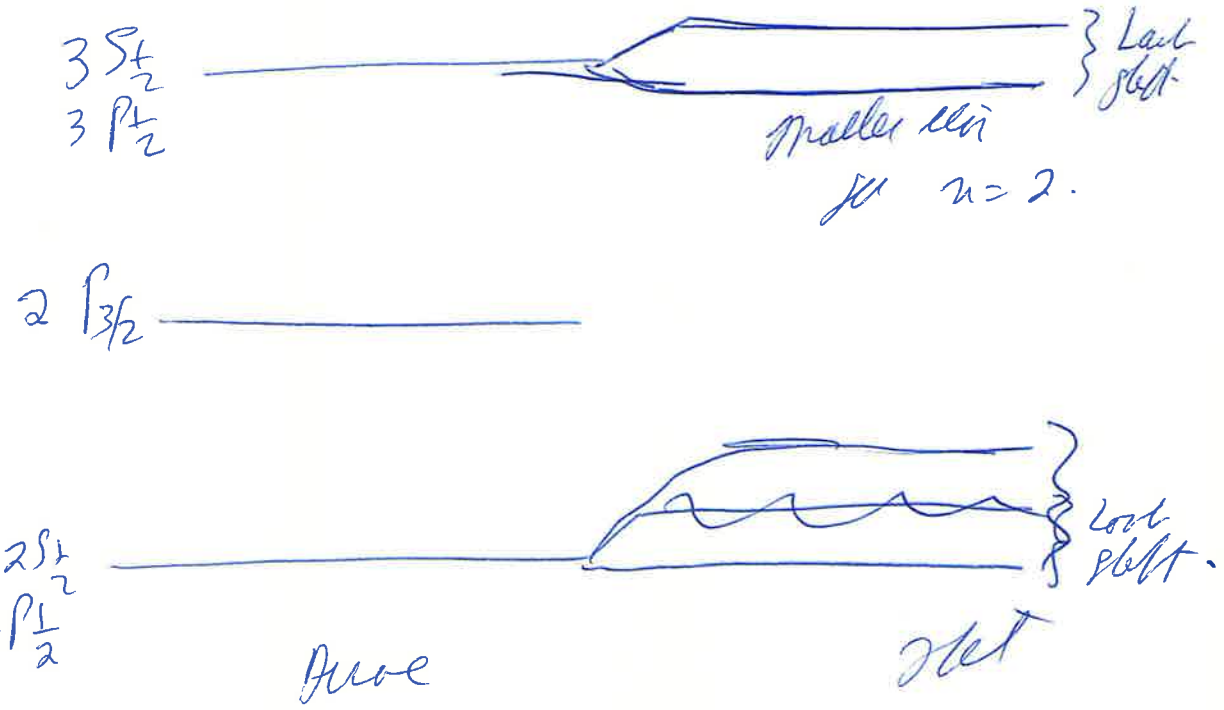
Kuhn's series Rev. Sci. 20, 202, 127 (1952)

2 lines of H studied

3 → 2

confirmed shift

No mention of hyperfine splitting



Pasternack P.P. SH 1113 (1939)

Letter suggesting S-level shift in H_2.
too large to be accounted for by finite
e electron or proton $\approx 10^{-13}$ cm.

Breit (1948) P.R. 74(65C) Magnetic moment of electron

refers to discovery of anomalous g by

by Nafe, Nelson, Rabi (1947) — suggests direct observations of anomalous moment of electron

→ (measurements on hyperfine structure in HJD)

Direct measurement by Kusch, Foley (1947) PR 72, 1256

(suggested by Rabi) using a magnetic resonance technique. (from the Zeeman effect in HJD)

Has of course referred to bound electrons

Later measurements have been for free electrons,

involving reduction of deflection of electron beams in a magnetic field. (also used by Crowley, Rich)

conducted by Lowrell, Rabi, Kusch (1954)

— infrared vid. Schupp, Rabi, Kusch (1961)

Wesley, Rich (1970) P.R.L. 24 1320

Cannot explain previous discrepancy
due to experiment of Wilkinson, Crane, (P.R. 130, 852 (1963))
which was re-evaluated by Rich (P.R.L. 20 967 (1968))
who used the W.C. result from

$$\left.\begin{array}{l} 1159\,622 \pm 27 \\ \text{to} \quad 1159\,549 \pm 30 \end{array}\right\}$$

, in clear disagreement with theory
α^3 terms in g have been calculated
by ~~Taylor~~, Peterman, Brodsky, Dufner
& Kinoshita

Rich's new expt. was in v. good agreement
with theory

Rich (1968) refers to 9 factors for muons.
$= 0.001\,1666(5)$

2 standard deviation higher
than theory

New expt.
due to Bailey, Bartl,
Brown, Jöstlein, Von der Haar, Picasso, Farley.

(2) Predicted Power

the Lamb shift & anomalous magnetic moment have been verified to high degree of accuracy.

$^2S_{\frac{1}{2}} - ^2P_{\frac{1}{2}}$ shift - Expt:	1057.77 ± 0.10 Mc/sec	(1947-53)	
Theory:	1057.70 ± 0.15 Mc/sec	(Lamb, Fredkin, Yennie 1960)	
anomalous magnetic moment * Expt:	$(0.001160 9 \pm .0000024)$	e/2mc	
Theory:	0.0011596 (Schupp Pidd, Crane (1961))		
$\left(\frac{g-2}{2}\right)$, anomalous magnetic moment = 2 for pure Dirac			
Bethe observed L-Shift 1040 Mc/sec			

approximate ratio differs from 2.

Then Baranger Bethe, Feynman. 1951
Karplus Klein, Schwinger: 1952

Earlier work: Kroll, Lamb-French, Weisskopf 1949

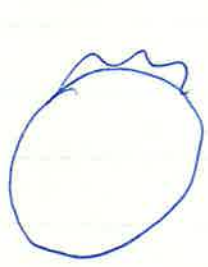
Yes calculated a crucial experiment for Q.E.D. If a rod fibre were used faster might have been involved but we are dealing here with pure electrons theorised so I think they could have been very badly shaken by emn, which in this case could not be ascribed to postulated apparatus which was excellent.

Renormable predictive power of Q.E.D
→ concept of renormalisability of Q.E.D
→ Dirac's Natural order of description of Observed or Future observation by Feynman need of some order & reality.

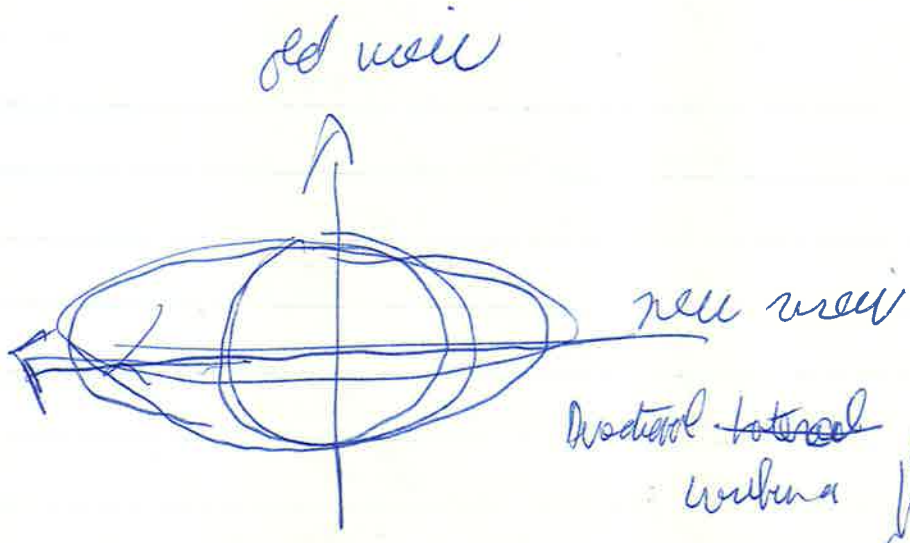
Other successes of theory include:— Prediction of positron & of meson but now theory was only invoked after the experiments

② Gell-Mann, Pais predicted regeneration of K_S

N.B. Quantitative predictions by theories
v. important:
Ex (1) Newtonian Mechanics, Ch Balance, Lavoisier
& Neptune
(2) Hydrogen spectrum '15 & Parabolas (1920)
(3) Lamb shift.



simple
normal science
the simple effect



paradigm shift

for the Heisenberg, decoupled in 1959, Jenkins the anti-proton decoupled in 1955 (acc. specially built for this).

④ Production of Λ^0 by $SU(3)$.

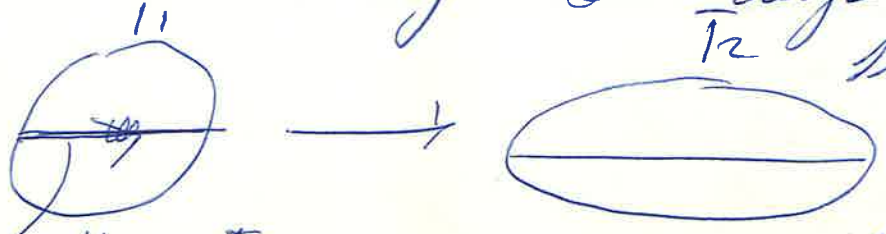
Conclusion So far a theory is in disagreement with experiment does not by itself become

1) theory is wrong
2) Mathematical assumptions are wrong etc

this is great advantage of S.F.D since fundamental theory ~~theory~~ works well.

but if strong interaction effects are involved we do not know whether 1 or 2 is right.

Second feature of this: If in the diagram theory agrees with experiment it is assumed that all the unessential features of the full theory — this can be visible theory & could be theoretically useful in producing a new theory which stands some appeal to the old theory see diagram below



stands successful features of T_1 assumed in the approximate theory.

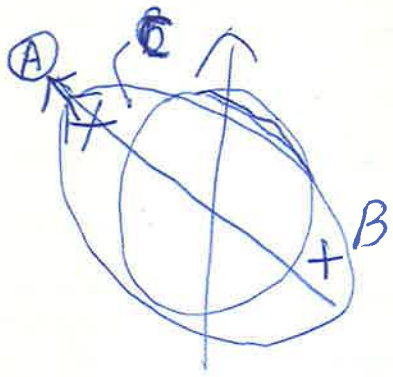
(approximate theory)

Ex analytic S-matrix theory can be regarded as this

last

Note on theory / experiment

In terms of the shift diagram non-ad-hoc/ad hoc distinction is drawn thus:—



Shifts are at first arbitrary mathematical expressions. A shift then enlarges along a direction in which a new experimental result can be accommodated by a stretch of the theory in that direction

the theory is e.g. designed to explain i.e. accommodate A at the head of the arrow.

(1) But the elongation may also explain or predict or accommodate a novel result as at B, outside the old theory, but not a result for which the theory was devised, viz. to explain A. The theory's is non-ad hoc w.r.t. B.

(2) But theory may be stretched in direction of A and also make a prediction of a fact C in the same direction. B must then be a chronological prediction for it to rank as a + point of novelty for the theory. Einstein could be described as predicting, the anti-proton, the neutrino, when theory was actually used to 'make experiments' or (3) B may be

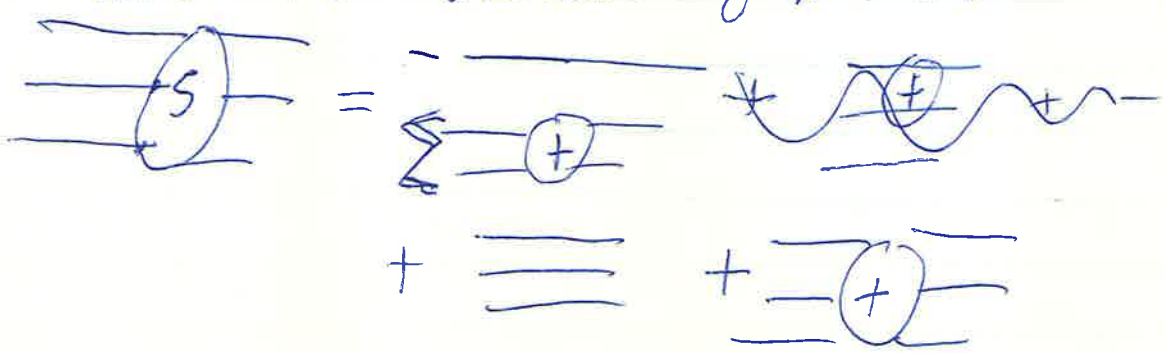
Each particle is part of every other particle including itself. Eq $N = \Pi N(N)$

cf. the philosophy of Chew-Frautschi but whereas the constituents of particles are only those processes which are permitted by symmetry-based selection rules, e.g. we cannot regard Λ^0 and a $\bar{K}N$ bag and therefore cannot be considered. Calculus cannot be used.

We can no longer talk of elementary particles or attempt to analyse. Composite particles in terms of a subset particles — as one does in a democracy.

However the bootstrap appears to apply only to hadrons and has not been extended to include the leptons, electromagnetic interactions, for which long range forces invalidate the assumed connectedness-structure of the S-matrix

or



Hadrons + electrons according to Chew (Analytic S-Matrix p 76) are connected with the symbols of measurement, the means of macroscopic observation — they all reflect a different "hadron" Hyperion which is to be understood in terms of observations conducted by physicists

R. M. P. 21 (1949) 305, Weisskopf

very good review of electron self energy problem

Meaning of fusion of an electron is due

Electron interacts with latest fact about the Coulomb Potential. electron probes away vacuum electrons → shows of. extension $\sim \hbar/mc$.

Zero-point field oscillations,

$\overline{(x)^2}$ now becomes finite

and $(\dot{x}^2)$ because of logarithmic divergent effects then become we no longer deal with a point charge. (In order to keep coherence $\langle x^2 \rangle$ as now equal to certain very short λ's, rotations between λ/mc => classical radius]

Vacuum polarization is a different effect due to displacement of pair to the electric field of the electron (over) above the effect

Dirac P.R.S.A 114, 24 (1927)

treats interaction of 1 boson system of particles with another
fermion system — derives effective Hamiltonian.

Also E.M-field is analyzed with energy, phase as
canonical variables — zero Hamiltonian
obtained. — fails to use feature in fields
of electrons:

wave theory starts from S.Eq. — Expand $\psi = \sum a_n u_n(x)$ —
as in der quantized — this is the wave picture. Then
from N-particle S.Eqn a similar formalism is developed
when a symmetrized wave function is employed, this means
equivalent of wave; particle picture

Dirac P.R.S. A 114, 710 (1927)

after theory of quantized radiation field
to the case of Bose/Fermi statistics
denies the transformation theory

Jordan > Pauli Z. f. Ph. 47 151 (1928)

derive. invariant commutation relations between free fields at different points — introduced δ-function

also consider commutation relations for field written as Fourier components

thus they build up $\psi = \sum a_n u_n$ and then

investigate properties of the ψ's as Dirac's variables

— actually they deal with the e.m. field in the absence of interaction > are interested in invariance of the theory

Heisenberg > Pauli Z. f. Ph. 56 1 (1929)

develop general theory of the E.M.

very Lagrangian formulation → Hamiltonian

→ canonical quantization → Fourier

analysis — thus generalizing the work

of Jordan > Pauli for free e.m. field

Heisenberg, Born & Jordan Z. f. Phys. 59, 169 (1930)

Continue previous paper, give general analysis of equations. Use matrix formulation for e.-electromagnetic

Jordan, Klein Z. f. Phys. 45, 751 (1927)

extend Jordan's work to a system of interacting particles (Bose-Einstein) uses both wave nature (de Broglie wave) + particle nature known to be equivalent (as in Duane) who considered interaction of independent particles with matter fixed system - e + photons + atoms) photons are independent

Jordan, Wigner Z. f. Phys. 47, 631 (1928)

extend Jordan, Ideen's work to the
Coll of Fermions — introduce anticommutable
relations

Fock Z. f. Phy. 75, 622 (1932)

discuss equivalence of configuration space
& 2nd quantized formulation starting from
Schrödinger theory. The quantized wave functions
are expanded in a series of configuration
spaces for 1, 2 ... particles (the Fock space).
He goes on to discuss connection of quantized
wave function & the quantized wave equation
by excluding time dependence.

β-D

The research of Fock[2] on n dimensional configuration spaces would do not commute with N.

Physical Review (1949) 15 p. 1023

derives transformation from configuration space to the space of quanta (occupation No space) by defining a unitary transformation S, s.t. that

$$\phi(n_1, n_2 \ldots x_1 : t) = \sum_{n_1, n_2} (n_1, n_2 \ldots x_1 \ldots x_n | S | n_1, n_2 \ldots) \psi(n_1, n_2 \ldots t)$$

similar development to Fock.

Heisenberg Z. f. Phys. 120 513 (1943)

Observable quantities in the theory of elementary particles that would not ordinarily depend on (energy loss, scattering x-sections) fundamental length $\sim 10^{-13}$ cm.

Heisenberg Z. f. Phys. 120, 673 (1943)

Corrections to above program. weak coupling of interactions

Feynman P.R. 74 (939) 1948

derives cut-off in classical electrodynamics by imagining the light cone (as in Bopp)

Yu P.R. 74 (1430) 1948

offers clone also to Q.E.D. & finds renormalizations.

Nelson Tomonaga developed for rel. mm. formalism in 1943 — Dyson applied it to Bethe's suggestion of renormalization & deflocated Schwinger's invariant subtraction procedure. (Schwinger woke a reference but to acknowledgment to Tomonaga's work)

Feynman P.R. 84 (108) 1951
develops a new & clearer calculus w/ Q.E.D.

Fujinen P.R. 80 (440) 1950
gives proof of his 1949 results based on the Lagrangian formulation of Q.E.D.

Schwinger P.R. 73 416 (1948) (Letter)

discusses his method and applies
to magnetic moment
Lamb shift
reduces emission to scattering
— no reference to Tomonaga.

refers to Kusaka
N.R. they reached
at Shelter Island Conference.

Tomonaga P.R. 74 224 (1948)

discusses his work — similar to Schwinger's
— based on Pekeris's 1947 work also Japanese
developed calculations quite similar to
Schwinger's even the Feynman diagram
techniques. — { discusses magnetic moment
Lamb shift
relativistic emission to scattering

Schwinger II (1948. P.R. 74 1439) refers in a footnote
to Tomonaga's (1st published
in Japanese in 1943)

Gell-Mann, Pais P.R. 97 (1387) (1955)

predicted the 2 - decay modes of the $K_0, \bar{K}_0$ in terms of regenerates of C. (based on charge independence ideas which later strangeness)

Pais & Piccioni P.R 100 1487 (1955)

suggested the regeneration experiment as a test of the Gell-Mann - Pais theory

Gell-Mann P.R. 92 833 (1953)

extends charge independence to the hyperons

Nishijima Prog Theor. Phys. 13 p.285 (1955)

summarizes earlier work (1953-1955) introduced Y-charge (strangeness)

(1st denoted in Prog Theor Phys 12, p107 (1954))

$\Gamma_{ae} = \sum_u \Gamma_{au} \Gamma_{ue}$ if we can measure $a \to c$

$\Gamma_{au} = \Gamma_{au} \Gamma_{ue}$.

In q.th. theory $\Gamma_{au} = |\phi_{au}|^2$ $\Gamma_{ue} = |\phi_{ue}|^2$ $\Gamma_{ae} = |\phi_{ae}|^2$.

and $\Gamma_{ae} = \sum_u \Gamma_{au} \Gamma_{ue}$

replaced by

$\phi_{ae} = \sum_u \phi_{au} \phi_{ue}$.

~~For a path~~ generalize to necessary intermediate points on a path.

Probability to path in region R is classical

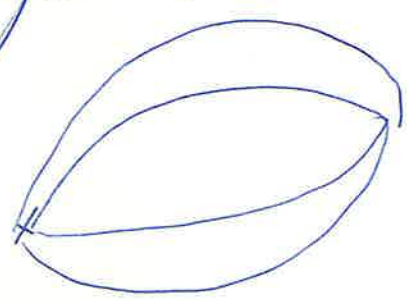
$= \int_R P(\ldots x_i, x_{i+1}) \ldots dx_i dx_{i+1} \ldots$

But in q. Mechanics is $|\phi(R)|^2$.

$\phi(R) = \int_R \Phi(\ldots x_i x_{i+1}) \ldots dx_i dx_{i+1} \ldots$

This is the Feynman Path integral.

Probability that path lies in a region of Space time.



Probability

Contribution to ϕ from a particular path is $\exp i/\hbar\, S[x(t)]$ $S = \int L(\dot{x}(t), x(t)) dt$ along the path in question

ferm $\phi(x) = \lim_{\varepsilon \to \infty} \int_R \exp\left[\frac{i}{\hbar} \sum_i S(x_i, x_i) \frac{dx_{i+1}}{A} \right]$ —

Z wavefunction

wave-function case out as

$$Z = \int_{R_i} \exp\left[\frac{i}{\hbar} \sum_{i=-\infty}^{n-1} S(x_{i+1}, x_i) \frac{dx_{i+1}}{n} \right] —$$

Z solutions S/Eqn.

ferm $\Psi(x'', t'') = \int \cdots \int \exp\left[\sum_{i=n}^{1} S(x_{i+1}, x_i) \right] \Psi(x'(t')) \frac{dx_n \cdots dx_1}{A \; n} —$

→ classical result $\Psi(x'') = e^{\frac{i}{\hbar} S(t'', t') \Psi(t')}$ / constant to Hamilton's principle

by stationary flow argument.

classical $B(t'', t') = \langle q'' | q' \rangle = B(t'', t_n) B(t_n, t_{n-1}) \cdots B(t_1, t')$

$$\frac{e^{\frac{i}{\hbar} S(t', t_n)}}{\rightarrow e^{\frac{i}{\hbar} S(t'', t')}}$$

$|q''|q'|^2 =$ conform.

in a dens

1.0. in classical limit

$$(q_2'', q_1') = B(t_2'', t_1') = e^{\frac{i}{\hbar} S(2,1)}$$

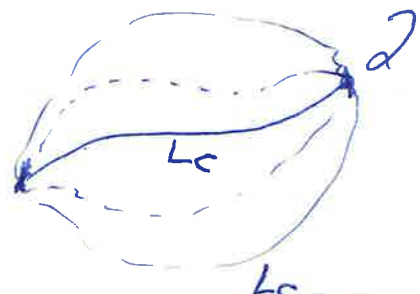
$$= B(2 t_n) B(t_n, t_{n-1}) \cdot B(t_1, 1)$$

In Q. Mechanics $\longrightarrow \int \cdots \int dt_1 \cdots dt_n \cdot B(\,) \cdots B(\,)$

$$= \int e^{\frac{i}{\hbar} S(2,1)}$$

this is the Feynman path integral

amplitude from 1 to 2 is sum over all possible paths from 1 to 2



In classical limit $(2,1) = e^{\frac{i}{\hbar} S_c^{L_c}(2,1)}$

Q. theory $(2,1) = \sum_L e^{\frac{i}{\hbar} S_c^{L}(2,1)}$

L_c is the classical path, L an arbitrary path

S_c^L is classical action along the path L

Toll P.R. 104 1760 (1956) investigates relation
between dispersion relations
& dispersion relations
is an integral formula relating a dispersive
process to an absorptive process.
For dispersion of light in a dielectric
cf. Kronig & Breit R.N.P. 4, 471 (1932)

$$n(\omega_R) = 1 + \frac{c}{\pi} \lim_{\varepsilon \to 0+} \int_0^\infty \frac{\alpha(\omega_2)\, d\omega_2}{\omega_2^2 - (\omega_1 + i\varepsilon)^2}$$

relation between dispersion relation & causality
first investigated by Kramers (1927) & Kronig (1926 and 1942)

Physical argument to exclude absorption from the complex
a higher order excitation to coherent scattering.
by photon scattering → photon absorbed + photon emitted

↓

if conservation laws prevent
decay of excited state into
its real ground state - elastic
virtual

Non real absorption → Im. coherent scattering amplitude
virtual " → real part . . . . .

10. Imag. (Scattering) → Total absorption at incident energy.
(Bohr, Peierls, Placzek, 1939) Kemble (1932)

Real (scattering) → ∫ all processes for.
absorption. coefficient.

Une absorption et toujours
toutes N. E. sont absorbé
Certaines à energy change et d'autres
N. E. sont reflected in the incident
direction process.

Goldberger Ph. R. 97 508 (1956)
refers to Gell-Mann, Goldberger Thirring P.R. 95 1612 (1954)
for extension of Kramers-Kronig to field theory
in perturbation theory.
He now extends to non-perturbation level

Gell-Mann and Goldberger

Salzberg P.R. 99 979 (1955)
extends the work but looks to
forward scattering amplitudes

Gell-Mann considers particles → forward scattering is
F.T. of functions which vanish for no values
of argument → analytic → dispersion relations

Chew > Low P. R. 101 1571 (1956)

apply the Low equations (as derived by Wick (1955)) to a Stable model — the Chew model introduced by Chew in P. R 95 1669 (1954).

Chew, Goldberger, Low > Nambu (1957) P.R. 106 1337 and 1345

extend theory to include pole record and derive the Low equations by a dispersion theory approach — 1st to do this in the Stable limit was actually Dehme (P. R 100 1523 (1955), 102 1174 (1956) who extended dispersion relation to the forward direction.

Low P.R 99 979 (1955)

derives the Lorentz equations by direct Transformation

$x \rightarrow x'$ results are in terms of renormalized

Mass, coupling constants — cf Taam Dancoff.

Ratf > Breit R. D. P. 4 471 (1932)

Review article on "Optical dispersion"

does not quote dispersion relation:

refers to Wolf > Herzfeld Handbuch der Physik (1928)

p. 480

Mandelstam P.R. 115 1741 (1959)

derives explicitly the analytic properties of the 4th order box diagram for scalar particles — proves the Mandelstam representation, but also states what for different names → amplitudes → singularities in the complex plane → local domain of the Mandelstam representation.

Then for fixed negative t. Mandelstam proves Lehmann integral is an analytic function of s with no singularities in the Lehmann plane. a value normal threshold

$$A^{(4)}_{(s,t)} \propto \int_{4m^2}^{\infty} \frac{\mathrm{Im}\, A(s',t)\, ds'}{s'-s} \qquad (1)$$

then from full Feynman ∫ for A^4 exists $\mathrm{Im}\, A^{(4)}$ in closed form. ∴ how it is an analytic function of t except for pairs cut — possible look at the double dispersion integral

Rendel Harris P. R. 115 1752 (1859)

~~Cardwell~~ derives coelibes & pelicutales
avis from coagulat, ululat- (for interesting)
relate ter rulod to ~~Fr. Hyde~~ Egypt-Nyx.

Rendel Harris N. C. 15 658 (1960)

derives pest & Rendel Harris op. cum amorabit
field theories — non-perturbier approach.
— Cardwell pest & R. Neb. not studied.

Rendelstein N.C. 30 1127 (1963)
descuss cuts in the J-plane.
prove A+B cut is Jones

Rendelstein N.C. 30 1148
prefers the Two Regdelstein cuts in the J-plane.

Amati - Stroyellini - Fubini N.C. 26 (890) (1962)
introduced kinematic l cut in the J-plane
in order to keep fixed.

Mandelstam (1963) Ann. Phys. 21 p-302.

discusses the problem of how omitting C.D.D terms in N/D solution is equivalent to onset obtained by analytic continuation from Regge-region to the complex plane of maximal analyticity of the second Riemann sheet

Oleno P. L. 135B 745 (1964)

Axiomatic treatment of S-matrix theory
refer to work of Sawson.
Similar to his book. (and Eden et al)

Wheeler P.R. 52 1107 (1937)

introduces the scattering matrix into scattering theory in his discussion of Resonating Group structure

essentially he writes sols

$$f_{j2} \; e^{-ikr} + C e^{ikr}$$

↳ scattering matrix element

He refers to it as scattering matrix.

Chew Physics 1 77 (1965)

discusses S-matrix theory, reasons why there is an increased — old revived theoretical fell in love of democracy — a rise of electromagnetic long-range forces for permanent. — quantum electrodynamics again used long-range forces.

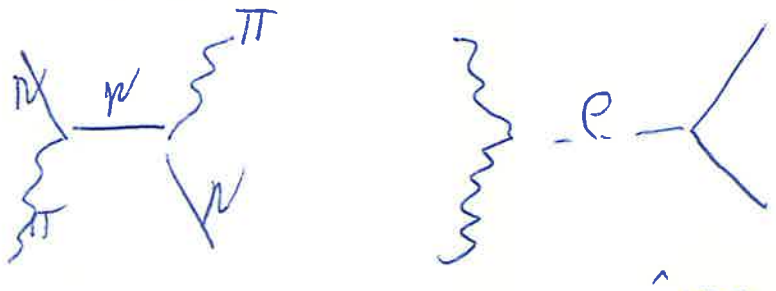
"Is our physics, mad d, matrix it possible for one isolated system to observe another,"

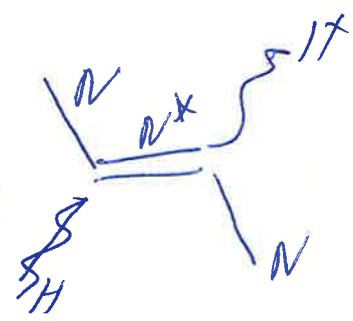
Ahers
~~Ahers~~ Zemach 138 B 1231 2305 (1963)

complete NN & NN̄ stretch calculation.
V. good introduction to the literature relatively.
Feynman forces are complex & the nucleon
& the constituents.
Here particles can appear as a constituent in a
composite & as the composite itself
N + π can be considered each N.
Simplest universe might be.

N = π N (N) π = N N̄ (π)

does not add in practice. N enough does not matter it
π is very tightly bound. pure NN̄ π enough
we should consider πe t̄ t α ... as contrib. for π



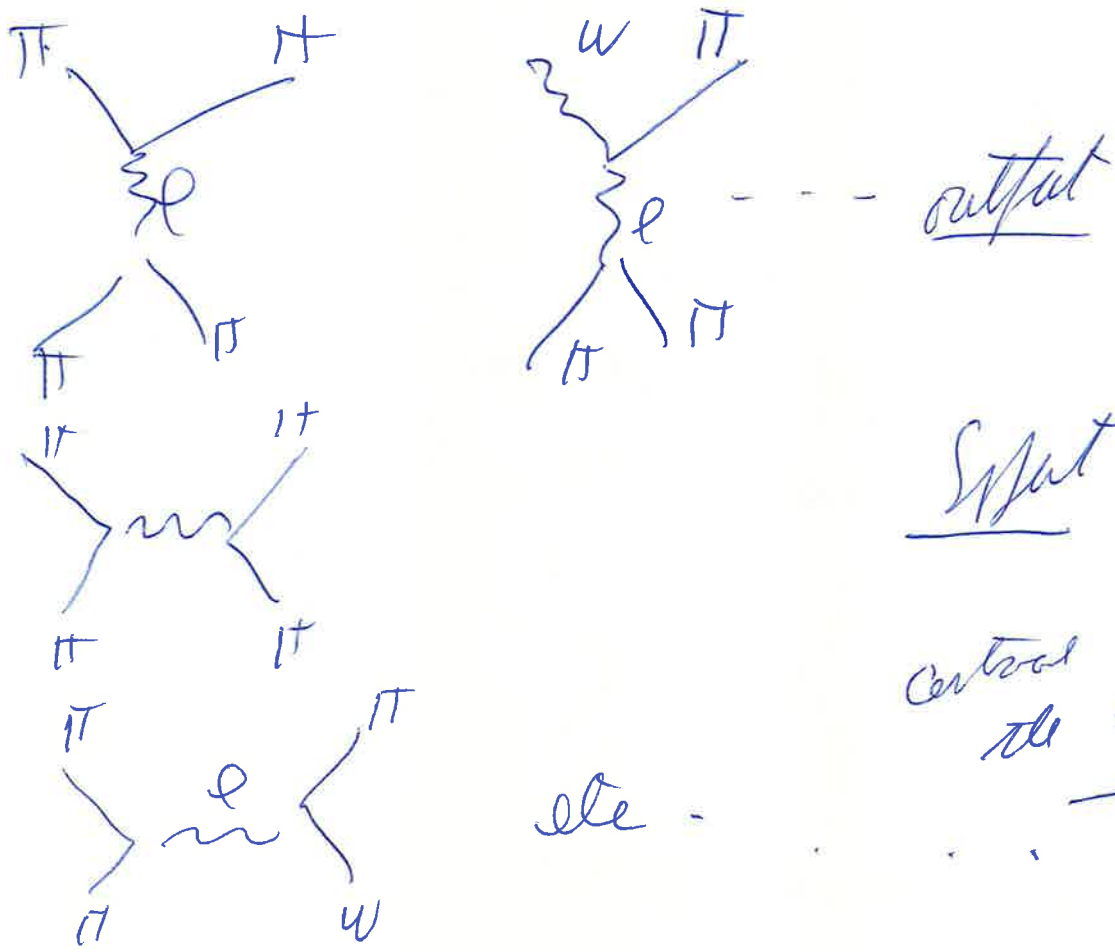


e enough not very important

Zoharaya, Zeeud. P.R. 128, 849 (1962)

V- gher Pmeson Interaction.

In Regge Model, each particle is assigned an energy-dependent parcelle (Fermion) coupling constant, so amplitudes for the reactions are determined by energy dependent functions entering the coupling constants or for elementary particles.



Chen, Rendtorff, Randelscan A.R. 126, 1202 (1962)

Dolan, Hon, Schmed, P.R. 166, 1768 (1968) FSRK inhibitor

Harari P.R.L 23, 562 (1969) Double diffusion

~~III~~
Jacob 1969. Proc. VIII — — —

Venezian Nuovo Cimento 57A, 190.

Schmid. P.R.L. 20 639 (1968)

Dolen Horn : Schmid P. R. 166 1768 (1968)

geen very clear extrapolation to F. E. S. R.
Contrast does low energy S-channel
resonances dual t channel Regge trajectories
or parallels N N resonances gold & trajectory

Hite (1969) R. M. P. 41 goes for reference
on Regge theory also.

Bootstrap

Swetnam Phys. Ed. 8 (1973) p 325

refers to Chem (1968) Science 161 762

(1970) Physics Today 23 (October)

End Index Phys > refs

1) Constituent of a composite

2.) Forces between constituents to provide the binding force

3.) the entire composite.

Lee (1972) Physics Today (April) for scaling symmetry

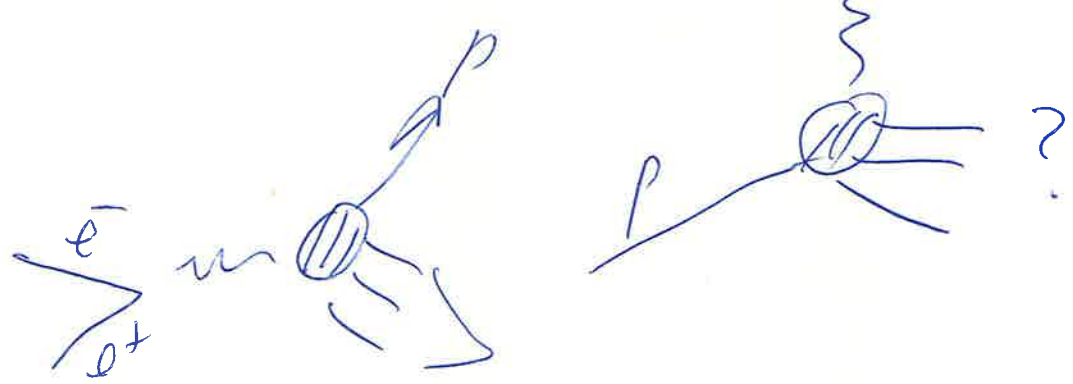
Partons introduced by Feynman

$e^- + p \to e^- + ?$

$e^- + e^+ \to p + ?$

Inelastic reaction.

proton structure of p



also chez Yang → scaling

Interesting parallels between the ideas due to Gell-Mann

Alvensleben (P.R. 131 2305 (1963)) on cut-offs

Fulco, Shaw, Wong (P. RD 137 1242 (1965)

use cut-off in a calculation of N^* & ρ and π^2 mesons
(due to overlap of particles with spin 7, 1))

↳ states "the crystal feature which permits a particle to appear as a constituent in a state and on the contribution of the form that the B.F. of the composite is comparable to the masses of the constituents themselves - the strong attraction which binds nucleons in the shape of heavy nuclei

B. Lee P.R. D5 (1972) p. 823 Proves renormalizability of Weinberg's theory. He says

" e.m., weak interactions are both mediated by Yang-Mills vector bosons — due to higher symmetry of the vacuum, the would-be Goldstone particle a the gauge vector particle, which would have only 2 transverse polarizations in the normal case, combine together to produce a massive-vector boson.

Thus higher symmetry of vacuum is used to generate the W-particle, the Goldstone bosons are eliminated, & the theory, being of Yang-Mills type can be renormalized

Yang, Mills P.R. 96 (1954) p. 191.

introduce isotopic gauge field in analogy with electromagnetic field.

Then q.m. case $\psi \to \psi' = e^{i\alpha}\psi$

α depends on x, y, z, t. , α is "contained" by introducing the e.m. field A_μ which obeys

$A_\mu' = A_\mu + \frac{1}{e}\partial\alpha/\partial x_\mu$.

$\psi = S\psi'$
ψ is isotopic spin $\frac{1}{2}$ in 2-comp. wave function

For isotopic gauge transformations we introduce a gauge field B_μ

$$B_\mu' = S^{-1}B_\mu S + i/g\, S^{-1}\frac{\partial S}{\partial x_\mu}.$$

They set up field Eqs for the B' field and-

the B field is used to counteract the dependence of S on x, y, z, t. This is the generalized-

the role of the ordinary concept of isotopic spin.

Regge (1959) N. Cim. 14 951

introduces complex a.m. in N.R. S Equation
and uses poles to show analytic
properties of scattering amplitude as
function of energy, scattering angle to
derive formally the Mandelstam representation.

Collins Regge theory, Particle Physics
Physics Reports C. 1 (1971) p 103-234

See also on Alessandrini, Amati, Bellac, Cleve
Operator approach to dual multiparticle
theory Phys. Rep. C 1 (1971) p. 269.

Pade' approximant $P^{(a,n)} = \frac{P_N(z)}{Q_M(z)} = f(z) + O(z^{N+M+1})$

↓
related
problem

approximants problem by related problems
useful zeros. Polynomials.

refer to Buchholz, H. Dobrev relativ dynamics (1967)

Irreducible $\mathcal{C}, A_2$ degenerate

$\mathcal{W}$

for low on the Poincaré trajectory:

major problem remains

e.g. why are Irreducible distinct

why does enclose degeneracy occur.

We can guess Verma core / counter

$$V(S,t) = q \cdot \frac{\Gamma(1-d_S(S))\,\Gamma(1-d_E(t))}{\Gamma[1-d_S(S)-d_E(t)]}$$

→ plateau d_S = slight

↑ Pole double pole.

→ Bopp generalized term., related F. to S. R.

Kogut & Susskind (1973) Physics Reports (1973) no 2
p. 76. (June 1973): The Parton picture of elementary particles:
remarks that "It seem to be very unlikely that
partons are really point particles."
"& partons will be resolved even further into yet
another hierarchy of constituents - -"
at shorter & shorter distances we may encounter
more & more structure.

Papers to consult

Bankruptcy & determinism. Mackay. New Scientist vol. 41 p. 824.

Lovelsberg > Evans. Br. J. Phil Sc. 21, 343

Ball. P. R. P. 38 444 (1966)

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Ohnuki & Kamefuchi P.R 110, 1279 (1958)

Stolt > Taylor

Resnick > Greenberg P. R. 136, B248 (1964)
P. R. 138, B 1155 (1965)

Harte > Taylor P.R. 138 2043 (1969)

Landshoff > Stapp Ann. Phys. 43, 52 (1967)

Steinmann Nuovo Cimento 44, 155 (1966)

Popper "Probability" B. J. Phil. Sc. X, 25 (1959)

Bootstraps

NN* ✓ Chew PRL 9 233 (1962)
✓ Symph > Vd Gontar PR 130, 1177 (1963)
✓ Allen > Zemach " 131 2305 (1963)
✓ Ball > Wong " 133 B 119 (1964)
✓ Frautschi > Walecka " 120 1486 (1960)
Falco, Shaw > Wong: P.R. 137 B 1242 (1965)

P Zachariasen P.R.L. 7, 112 (1961)
Balazs P.R. 128, 1939 (1962)
129 812 (1963)

Parton
Drell, Levy, Yan P.R.L 22 744 (1969)
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Harte, J CERN Th. 1527 (1971)

E.R.P P.R. 41 772 (1935) Marguel P.R 49, 240 (1936)
Bohr 48 696 (1935)
Furry 49 493 (1936)

Chew, Low P.R 101, 1570 (1956)

C.G.L.N. (Low Feller) P.R. 106, 1337 (1957)
Rechenberg, Zemach (Pocketlap) P.R. 128 849 (1962)
Nevello P.R. 132 844 (1963)
Hamilton, Deruelle, Redmond P.R. 135 B515 (1964)
Carruthers Ann. Phys 31 410 (1965)
P.R. 133 B497 (1964)

Hite P.R.P. 41 (1969)
Mandelstam 112, 1344 (1958) P.R. 123, 1478 (1961)
Chew, Frautschi: P.R.L. 7 394 (1961)
8 41 (1962)
Chew, Mandelstam P.R. 119, 467 (1960)

chew : Frautschi P.R.L 7 394 (1961)

Suggests all particles are regge-poles. Nucleon-nucleon partial and inelastic cross sections

chew : Frautschi P.R.C. 2 41 (1962)

contours des lieu d'argument

chew P.R.L 9 233 (1962)

Peripheral potential for $N + N^*$.

Nucleon = pion + nucleon (cuts of N^2)

Zachariasen P.R.L 7 112 (1961)

Pole terms appear to

chew : Mandelstam (1960)

chew : Frautschi P.R. 123, 1478 (1961)

in strip approximation.

chew : Mandelstam P.R. 119, 467 (1960)

N/π inelasticities to the pole strip

cuts for - force : scattering

Henley / Thirring Elementary Q. field Theory p. 1 (1962)

"The Normal Schrödinger & Klein-Gordon wave functions ψ can also be regarded as classical matter fields ψ(x) ∴ to start to quantize them

"Inconsistencies arise when the classical e.m. field is quantized" — refer to Bohr, Rosenfeld — criticized by Rosenfeld.

Observables local fields $\phi(x)$ is not an operator in Hilbert space. + state vect ψ such $\phi(x)|\psi\rangle$ for a realm. e.g. but averaged over a small vol. a^3 is all right fluctuations in $\frac{1}{a}$ with $a \sim 10^{-8}$ cm fluctuations in coulomb field ⇒ Coulomb potential, but frequency is ~ 137 × frequency electron in ground state, so electron just wobbles. Detectible effects should clearly of electron for a region of $\sim a^3$ cm. Vacuum polarization effect on Lamb shift.

In N.R. $\langle 0|0 \rangle \{N_{\omega_1}(t), N_{\omega_2}(t')\} = 0$

But in Rel. case. $N_\nu = 0$ for ν when ν any $\hbar/mc$ decay from volume containing the particles (? equal time commutator)

Combining $E = mc^2$ and $E = \hbar\nu$ ——— (1)

Modifies our concept of particle

In N.R. limit they appear as points, i can be confined in arbitrary small region of space

In Rel. limit the particles have roughly the size of their compton wavelength $\hbar/mc$

Also from (1) $\lambda = c/\nu = \frac{c\hbar}{E} = \hbar/mc$

as $c \to \infty$ $\lambda \to 0$ so particles behave like points.

$\left(\text{as } \lambda = \hbar/p \to \hbar/mc. \right)$

electron in Hydrogen is spread in finite region as S-state is reduced since its pic does not permit it to take full advantage of the proton singular part of the Coulomb potential

Heerbrug. Physical Records & J. Story

p. 154 Attendant theory of the op. can be regarded as a "denial" theory of patter wear, despite cases in the con. to interpretation of the Weltanschauung especially different from that of the foregoing dates. The questions arising into the op can all be considered in terms of those two lines set in the questions as Russell's op., see the all fourteen of 4 results as yet